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REFINING SAMPLING PROTOCOLS FOR INVENTORYING INVERTEBRATE BIODIVERSITY: INFLUENCE OF DRIFT-FENCE LENGTH AND PITFALL TRAP DIAMETER ON SPIDERS

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ABSTRACT. The limited resources available to inventory biodiversity and conduct ecological monitoring requires efficient protocols for sampling with pitfall traps. Here we consider adding different length drift-fences to pitfall traps on spiders. Four different fencing treatments (no fence, or fence lengths of 2, 4 and 6 m) were evaluated in combination with three trap diameters (4.3, 7.0 and 11.1 cm). Three-way ANOVAs revealed no significant interaction effects between any combinations of fencing treatments, trap size or the spatial positioning of transects within the study site along which traps were arranged. Post-hoc tests showed fences significantly increased the abundance of individuals and richness of spider families, and species collected. Traps with 6 m fences were significantly higher in all of these variables than traps with 2 m fences. ANOSIMs revealed taxonomic composition differed significantly between fenced and unfenced traps at familial, and specific ranks. Among fenced traps, taxonomic composition was influenced primarily by trap diameter rather than fence length. ANOSIMs showed significant differences in taxonomic composition between each trap diameter for fenced traps. An optimal combination of fencing treatment and trap diameter was determined by constructing smoothed species accumulation curves for increasing numbers of traps. Four criteria were considered: equivalent numbers of traps, standardized cumulative trap circumference, standardized cumulative fence length (fenced traps only) and standardized cumulative handling time. For the same number of traps, 11.1 cm traps with 4 and 6 m fences collected the most species. At a standardized trap circumference, long fences were best, with all trap sizes catching similar numbers of species. When fence length was standardized, 11.1 cm traps with 2 or 4 m fences collected the most species. At a standardized handling time all traps caught very similar numbers of species, although most 11.1 cm diameter traps collected more species than other trap sizes and those with 4 m fences were most efficient. Given the similar performance of fenced and unfenced traps for standardized handling time, we outline reasons why unfenced traps may be best.

Keywords: Arthropods, barriers, guides, inventory, sampling methods

Little doubt exists that global biodiversity is decreasing rapidly (Chappin et al. 2000; Pimm & Raven 2000; Purvis & Hector 2000). Calls have been made to inventory global species diversity (Wilson 1985; Raven & Wilson 1992; Stork & Samways 1995), however, there are inadequate resources available for this task (May 1988; Gaston & May 1992; Hawksworth 1995). Methods that sample taxa quickly and efficiently are needed (Colwell & Coddington 1995; Dobyns 1997). Additionally, limitations of sampling methods, or deviations from an accurate representation of community structure, must be known (Churchill 1993; Churchill & Arthur 1999; Skerl & Gillespie 1999). Rapid development and acceptance of standardized sampling protocols represents a key conservation goal as it facilitates comparisons between studies where to date, comparisons have been either tenuous or impossible (Coddington et al. 1991; Beattie et al. 1993; New 1999). Standardized sampling protocols have recently been advanced for ground dwelling ants and beetles (Agosti & Alonso 2000; Niemelä et al. 2000). Standardized methods will facilitate comparisons between studies and renew interest in their use for ecological monitoring.

Considerable refinements for collecting spiders have been made. Horizontal stratification by different spider families and species within habitats has long been known (Muma &

Muma 1949; Turnbull 1973, Merrett 1983). To target all habitat strata many different collecting techniques are required. Moreover, given the heterogeneous nature of spider communities, sampling needs to be conducted over different spatial and temporal scales (Churchill & Arthur 1999). Comparisons of methods to date include pitfall trapping, beating, sweep-netting, suction sampling with D-vac or other devices, extraction from litter by Tullgren funnels or hand, and hand collecting from different non-canopy habitat strata (Duffey 1962; Uetz & Unzicker 1976; Merrett & Snazell 1983; Coddington et al. 1991, 1996; Topping & Sunderland 1992; Edwards 1993; Churchill 1993; Samu & Sárospataki 1995; Dobyns 1997; Churchill & Arthur 1999; Standen 2000). The standardized sampling protocol advanced by Coddington et al. (1991, 1996) targeted spiders in all non-canopy habitat strata. Their collecting methods were beating, hand collecting looking-up, hand-collecting looking-down, and extraction of spiders from leaf litter with Tullgren funnels or by hand. They suggested that using pitfall traps in combination with the above methods might be beneficial. Considerable sampling biases and limits to data interpretation are known for pitfall traps (Greenslade 1964; Southwood 1966; Adis 1979; Spence & Niemelä 1994; Melbourne 1999). Despite this, many authors have found pitfall traps valuable in their collecting repertoire (Duffey 1972; Uetz & Unzicker 1976; Churchill 1993). Establishing a standardized pitfall trapping protocol for inventorying spiders is needed (Brennan et al. 1999).

Many advances in sampling with pitfall traps have been made. Various materials and designs have been used to construct invertebrate pitfall traps, including cups, cans, jars and troughs (Duffey 1962; Merrett 1967; Luff 1975). Refinements increasing capture success of spiders have included fitting aprons around pitfall traps; this increased the catch of clubionids, gnaphosids, salticids and thomisids (Cutler et al. 1975; Uetz & Unzicker 1976). Aprons may also reduce sampling error arising from alteration of microclimate, disturbance by mammals, flooding, and litter fall (Uetz & Unzicker 1976). Traps containing a killing/preserving solution collect more spiders than dry traps (Curtis 1980; Gurdebeke & Maelfait 2002), and adding detergent to ethylene glycol catches more linyphiids (Topping & Luff 1995). Funnels placed inside traps decrease captures, but by decreasing evaporation of ethanol can yield better specimens for DNA analysis (Gurdebeke & Maelfait 2002). With roughened surfaces on the interior of pitfall traps (including wear from reuse) collection of linyphiids declines (Topping & Luff 1995). Larger diameter traps collect more species than smaller traps (Brennan et al. 1999; Work et al. 2002). Large traps are more efficient than smaller traps when measured by handling time (Brennan et al. 1999). Size of rain covers has no effect on spider catch (Work et al. 2002). Length of trapping period can influence interpretation of community composition for linyphiids and other surface-active spiders, with longer periods of collecting preferable (Topping & Luff 1995; Riecken 1999). More traps collect more species (Samu & Lövei 1995), although taxonomic composition remains fairly constant with fewer traps (Niemelä et al. 1986; Riecken 1999). Consequently, where resources are limited, decreasing the number of traps, rather than sampling period, may permit more accurate interpretation of community structure (Riecken 1999).

Recently, attaching fences to pitfall traps to facilitate spider captures has aroused interest. Different authors have used the terms "barriers", "drift-fences", "fences" and "guides" synonymously and for different structures. Here "fences" refers to structures erected to guide surface-active animals into traps. These differ from structures erected to form an enclosure around traps, which limits the spatial area from which traps sample (e.g. Gist & Crossley 1973; Mommertz et al. 1996; Holland & Smith 1999). In savanna woodland and mown lawn of tropical northern Australia fences increase the catch of spiders and many dominant spider taxa. The effectiveness of fences, however, varies over time (Churchill unpub. data). The taxonomic composition of spiders collected also varies with trap design. Trap size differences (4.5 cf. 8 cm diameter traps) were greatest between unfenced compared to fenced traps (Churchill unpub. data).

Here we determine: 1) if fences increase spider catchability in the jarrah (*Eucalyptus marginata*) forest of temperate south-western Australia, and 2) if fence length influences taxonomic richness and composition? 3) For fenced traps, does trap size influence taxonomic richness and composition? 4) How many traps are required, and what is the optimum combination (trap diameter and fence length) for sampling spiders in this habitat? Our optimal combination is based on catching the most species using the: a) least number of traps; b) lowest sampling intensity (minimal cumulative trap circumference); c) least amount of fence; and d) least amount of time.

METHODS

Study site.—Spiders were collected from unmined forest surrounding Alcoa World Alumina Australia's (formerly Alcoa of Australia) Jarrahdale mine (32°17′ S, 116°08′ E) on the Darling Plateau, approximately 45 km southeast of Perth. The region has a Mediterranean climate, with hot dry summers and cool wet winters. Annual rainfall is 1200 mm, with most falling between May and September. Soils are highly weathered and composed of coarse ferrinous gravel (> 2 mm particle size) in a matrix of yellow-brown sand derived from a lateritic profile (Churchward & Dimmock 1989).

Vegetation at the site (450 × 250 m) was a tall forest (to 35 m) of jarrah and marri (*Corymbia calophylla*) trees. Other small trees (3–7 m) were present also; mainly Bull Banksia (*Banksia grandis*), and Snottygobble (*Persoonia longifolia*). These overtopped understorey species such as grass-trees (*Xanthorrhoea preissii* and *Kingia australis*), cycads (*Macrozamia riedlei*) and legumes (*Acacia*, *Bossiaea* and *Kennedia*). Leaf litter varied from 25–100 % cover and a depth of 1–40 mm.

Sampling spiders.—Effects of pitfall trap size and fence length on spider catchability were investigated using a three-way factorial design, composed of pitfall trap diameters (4.3, 7.0 and 11.1 cm), fence length (0, 2, 4 and 6 m) and spatial positioning of transects within the study site along which the pitfall traps were arranged. Pitfall traps were arranged as follows: 15 parallel transects were positioned 30 m apart. Along each transect 12 traps were positioned 14 m apart with each trap representing a different combination of trap size and fencing treatment (3 trap diameters × 4 fence lengths = 12 traps per transect, 12 traps × 15 transects = 180 traps). Transects were grouped into three sets based on their location within the site; southern (transects 1–5), central (transects 6–10) and northern (transects 11–15). This design permitted potential differences in spider catchability related to the spatial positioning of transect groups within the study site to be considered. For brevity, focus is restricted here to trap diameter and fence length.

Pitfall traps were clear plastic containers that varied in diameter but not depth (7.5 cm). Each trap comprised three plastic containers. The first was dug into the soil so that its rim was flush with the soil surface. The second was filled with soil, placed inside the first container, and left *in situ* for two weeks. This was to allow any disturbance effects caused by "digging in" the traps to abate (Joosse & Kapteijn 1968; Greenslade 1973). For trapping, the soil-filled container was removed and replaced with a third that was half-filled with Galts solution (Main 1976) plus 2 ml of detergent (to decrease surface tension). The use of this solution is no longer recommended. To ensure that the rim of the third trap was flush with the soil surface a small amount of soil was added where necessary. Traps were open for one week (12–19 September 1997).

Fences consisted of black plastic (200 um thick), approximately 25 cm high and buried 5 cm into the ground. They were aligned parallel to transects and secured with wooden skewers (0.25 cm diameter, 20 cm long) where necessary. Fences did not span the trap but were cut into two pieces and orientated such that an imaginary line joining the two fences together would bisect the pitfall trap into equal halves. Considerable care was taken to ensure that fence edges closest to each trap were not folded against the outer rim (which might have prevented a spider moving along the fence to fall into the trap). Traps were checked on the third day of sampling. Any litter debris that had fallen into the trap and was likely to reduce retaining efficiency was removed.

Adult spiders were sexed and identified to species level and assigned a code when no name could be found. Most species at Jarrahdale are undescribed and many older taxonomic keys are inadequate (Brennan et al. 2004). Juveniles, penultimate instar males and sub-adult females could not be identified with certainty beyond family level (and sometimes genus), so are not considered here. A reference collection of taxa has been deposited in the Western Australian Museum.

Data analysis.—Data were analyzed using univariate and multivariate analyses plus species accumulation curves (collectors curves).

Univariate analysis: Univariate analyses involved three-way and two-way analysis of variances (ANOVAs) that had Type III sums of squares (Underwood 1997). Dependent variables were abundance, and taxon richness at familial and specific rank. Factors were FENCE, TRAP and LOCATION. Levels for FENCE were the fence lengths 0, 2, 4 and 6 m. Levels for TRAP were the trap sizes 4.3, 7.0 and 11.1 cm. Levels for LOCATION were southern, central and northern.

Our full data set included all combinations of fence length and trap size across all transects. It was analyzed using three-way ANOVAs. Means for each trap size were derived from all traps comprising that size class (n = 60) and means for each fence length were derived from all traps comprising that fence length (n = 45); means for each location were derived from all traps from the five transects making up each location (n = 60).

For fenced traps, the effect of trap size on species richness was considered separately for each fence length. Three data subsets were analyzed with two-way ANOVAs: short fences (traps with 2 m fences); medium fences (traps with 4 m fences); and long fences (traps with 6 m fences). For each subset, factors considered were TRAP and LOCATION, with species richness being the dependent variable. Means for each trap size were derived from all traps within the fence length being considered (n = 15). Means for each location were derived from all traps within the fence length being considered (n = 15).

The effect of fence length on species richness was also considered separately for each trap size. Three data subsets, namely those from small traps (4.3 cm diameter), medium traps (7.0 cm diameter), and large traps (11.1 cm diameter) were analyzed using two-way ANOVAs. For each subset, factors considered were FENCE and LOCATION with species richness being the dependent variable. Means for each fence length were derived from all traps within the trap diameter being considered (n = 15). Means for each location were derived from all traps within the trap diameter being considered (n = 15).

Assumptions of ANOVA were considered before analysis. Abundance data were transformed to the log of the value plus one, while family and species richness were transformed to the square root of the value plus 0.5 (Zar 1984). Post-hoc means comparisons utilized Scheffé's S test (Day & Quinn 1989). Variance ratios (F) were considered significant when $P < 0.05$. All univariate analysis were performed using SPSS 7.5 (SPSS 1996).

Multivariate analysis: To determine the influence of different trap diameter/fence length combinations on the taxonomic composition of spiders, we used the Bray-Curtis (1957) measure to construct a similarity matrix on standardized root transformed data. The Bray-Curtis measure takes the form, $C = 2w/(x + y)$, where x is the number of adults collected by one method, y is the total number of adults collected by another method, and w is the sum of the lesser values for those species present in both samples. Standardization limits differences between samples that may arise through differences in abundance by dividing each count by the total abundance of all species within each collecting method. Root transformation reduces the influence of the most abundant species to dominate results (Clarke & Green 1988).

For ease of interpreting similarities, nonmetric multidimensional scaling (1,000 iterations) was used to represent data in two-dimensional ordination space (Clarke 1993). Confirmation of interpretations from MDS was obtained by hierarchical clustering, with group-average linking. Analysis of similarities (ANOSIMs, see Clarke & Green 1988) were used to test for differences in taxonomic composition between: a) unfenced and fenced traps (unfenced vs. fences of lengths 2, 4, and 6 m); b) trap sizes (4.3 vs. 7.0 vs. 11.1 cm diameter) irrespective of fencing; c) fencing treatments (unfenced vs. 2 m vs. 4 m vs. 6 m fences); d) fenced traps with different diameters (4.3 vs. 7.0 vs. 11.1 cm). An understanding, of which species made the greatest contribution to our MDS and ANOSIM results, was obtained through similarity percentages (SIMPER, see Clarke 1993) on root-transformed standardized data with cut-off contributions set at 50 %.

To determine whether results held at a higher taxonomic rank, we also constructed a similarity matrix on standardized, root transformed family level data. A Mantel's test (1,000 randomizations) using Spearman's Rank correlation (Manly 1994) was then used to test for a relationship between the species and family level matrices. Finally the MDS, hierarchical clustering, and ANOSIMs outlined above were repeated at familial rank. For brevity only the MDS results are presented. All multivariate analyses were performed using Primer 5.2.2 (Primer-E 2001).

Species accumulation curves: To determine an optimal combination of trap size/fence length we standardized at equivalent measures of collecting effort on randomized species accumulation curves (Colwell & Coddington 1995). Curves plotted cumulative species richness versus increasing numbers of traps, smoothed through 10,000 iterations. This method allowed integration of patchiness in species occurrences between samples that is lost when samples are pooled with classical rarefaction (Colwell 1994–2000). Curves were produced using EstimateS 5.0 (Colwell 1994–2000).

An optimal combination of trap size/fence length was determined for four measures of collecting effort, namely; number of traps, trap circumference, fence length and handling time. The optimal trap size/fence length combination for a standardized number of traps was that which gave the greatest species richness for 15 traps. Optimal trap size and fence length for a standardized trap mouth was determined by comparing the total species richness sampled when the accumulated circumference was approximately 206 cm. This value was chosen as it represented the maximum number of traps available (15) with a diameter of 4.3 cm. Nine 7.0 cm traps and six 11.1 cm traps were needed at this value. The trap size/fence length combination maximizing species richness at this intensity was considered optimal.

The optimal combination for a standardized fence length was determined by comparing the total species richness sampled when the accumulated length of fence used for those traps with fences was 24 m. This required 12 traps with 2 m fences, six traps with 4 m fences and four traps with 6 m fences. The combination sampling the highest species richness was considered optimal.

The optimal combination for a standardized handling time was that giving the highest species richness within a given period. Handling time for a single trap from each trap size was calculated by summing the mean of the following time measurements: dig in trap and install the fence (if appropriate); pour the trapping solution; set the trap; and collect the trap. Mean handling time represented five repetitions of each task. Cumulative handling times for increasing numbers of traps was calculated by multiplying the mean handling time for each combination by the number of traps used. Standardization of handling time was achieved when the accumulated handling time was approximately 23 minutes and 50 seconds. This value represented the maximum period that utilized all 15 traps for the most efficient trap size/fence length combination.

RESULTS

Pitfall trapping resulted in the capture of 610 adult spiders, representing 24 families and 63 species. As expected, increasing trap size and/or increasing fence length resulted in greater captures of spiders.

Univariate analysis.—For our full data set, ANOVAs revealed differences in mean spider abundance, plus family and species richness for trap size, fence length, and location (Table 1; Figs. 1–4). No significant interaction effects were found between the factors FENCE, TRAP and LOCATION.

Comparisons of means revealed traps with fences collected significantly higher abundances and more families and species than traps without fences (Figs. 1–4; Table 2). Also, traps with 6 m fences were significantly greater in these variables than traps with 2 m fences. All trap diameters were found to differ significantly from each other for family and species richness, but not abundance. Significantly increases in abundance were found only when trap diameter was increased from 4 to 11.1 cm and from 7 to 11.1 cm (Figs. 1–4; Table 2).

When individual fence lengths were considered separately in their own data subsets, the largest trap size always resulted in more species being caught. No significant interactions were found between TRAP and LOCATION (Table 3). For 2 m fences, 11.1 cm diameter traps caught more species than 4.3 cm traps (Fig. 5; Table 4). For 4 m fences, 11.1 cm diameter traps caught more species than 4.3 or 7.0 cm traps (Fig. 6; Table 4). For 6 m

Table 1.—F-ratios and significance levels from three-way ANOVAs of TRAP, FENCE and LOCATION on transformed spider variables for the full data set. Bold text denotes statistically significant difference at *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$; ^denotes non-significant trend at $P < 0.1$.

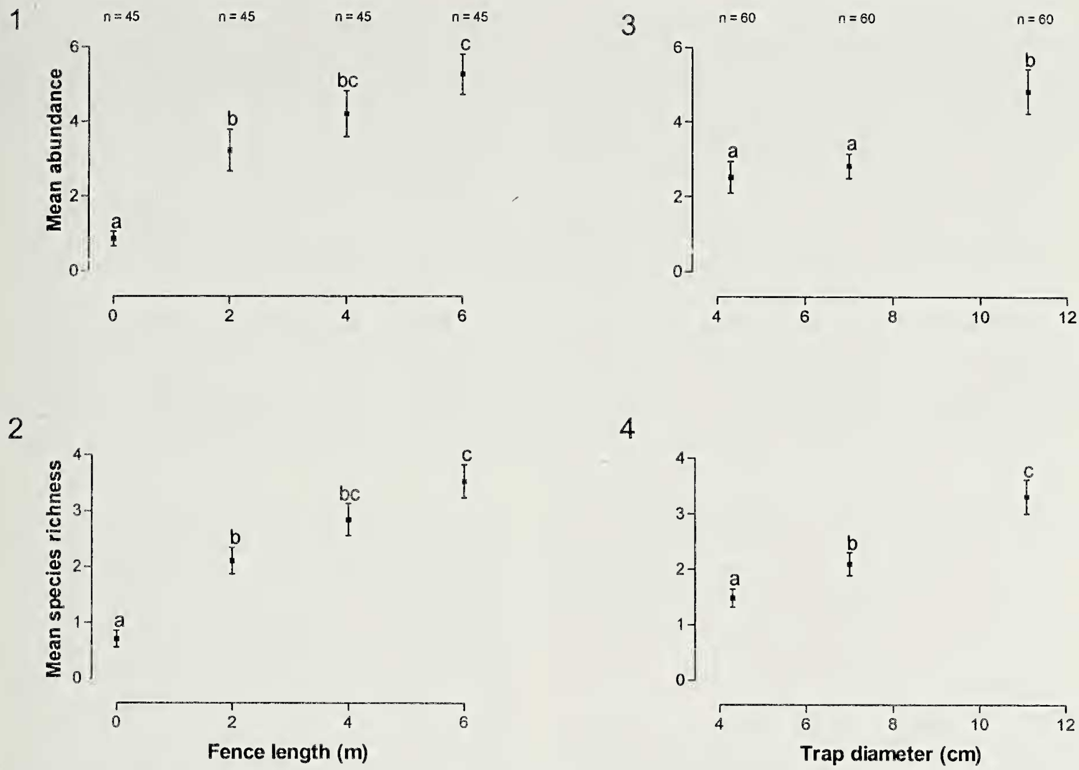
		Effects						
Data set	Dependent variables	FENCE × TRAP × LOCATION d.f. 12, 144	FENCE × TRAP d.f. 6, 144	FENCE × LOCATION d.f. 6, 144	TRAP × LOCATION d.f. 4, 144	FENCE d.f. 3, 144	TRAP d.f. 2, 144	LOCATION d.f. 2, 144
Full data set	Abundance	1.549	0.816	1.786	0.732	**39.171*** **	**14.171*** **	**14.277*** **
	Family richness	1.285	0.648	1.351	0.325	**34.347*** **	**18.095*** **	**4.146^**
	Species richness	1.471	0.881	1.912^	0.684	**39.885*** **	**23.161*** **	**6.259** **

fences, 11.1 cm diameter traps also caught more species than 4.3 cm traps (Fig. 7; Table 4). Unlike the full data set, however, no data subsets showed a significant increase in species richness as trap size increased from 4.3–7.0 cm diameter (Table 4).

Traps with fences caught more species of spiders for each individual trap size when fence length was examined separately in individual data subsets for the 4.3 cm and 11.1 cm diameter traps (Figs. 8–9). Unlike the full data set, no significant difference in species richness occurred between the 2 m and 6 m fences for 11.1 cm traps (Table 4). No significant interactions were found between FENCE and LOCATION for these data (Table 3). For the 7.0 cm diameter traps data subset a significant interaction occurred between the factors FENCE and LOCATION. We do not consider it further.

Multivariate analysis.—The taxonomic composition of spider species collected was quite similar between some trap diameter/fence length combinations (similarity > 60 %). Yet, between others, similarity was low (< 25 %). Multidimensional scaling permitted us to represent these similarities adequately in two-dimensional ordination space with a relatively low amount of distortion, stress < or = 0.1 (Figs. 10–11). Similar results were obtained with hierarchical clustering (Fig. 12).

Fenced vs. unfenced: The addition of a fence caused a marked alteration in species composition. MDS showed all traps with fences to cluster loosely together, and apart from traps without fences (Fig. 10). Similarly, hierarchical clustering showed fenced traps to form a terminal branch (Fig. 12). ANOSIM confirmed that when combined, traps without fences were significantly different in species composition to traps with fences, (unfenced vs. 2 m, 4 m and 6 m fences) (Table 5). SIMPER analysis revealed that almost 47 % of the similarity in species composition between unfenced traps with diameters of 4.3, 7.0 and 11.1 cm was attributable to a single species, *Myrmopopaea* sp. 1 (Oonopidae). This species, along with *Ambicodamus marae* (Nicodamidae) and *Longepi woodman* (Lamponidae), were also primarily responsible for almost 49 % of the similarity in species composition between fenced traps. Despite this, *Myrmopopaea* sp. 1 made only a small contribution (2.26 %) to the difference between



Figures 1–4.—Effect of increasing fence length (1, 2) and increasing trap diameter (3, 4) on spider catchability: (1, 3) abundance, and (2, 4) species richness. Different lower case letters denote significantly different means (established from post-hoc tests on transformed data, Table 2). Error bars are ± one standard error of the mean.

fenced and unfenced traps. This difference was determined by high and low abundances of many species (Table 6). Also, unfenced 7.0 and 11.1 cm traps were more similar in composition to fenced traps than unfenced 4.3 cm traps (Figs. 10, 12).

Fence length: No difference in taxonomic composition was found between any pairwise combination of traps with 2, 4 or 6 m fences. The only difference in taxonomic composition found was between fenced and unfenced traps. ANOSIMs revealed significantly differences in species composition between unfenced traps and those with 4 or 6 m fences (Tables 5, 7).

Trap diameter: When all trap diameter/fence length combinations were considered in the one analysis, no difference in taxonomic composition was found between the different trap diameters (Table 5).

Trap diameter (fenced traps only): For fenced traps, trap diameter, rather than fence length, appeared to be the primary factor influencing similarity in taxonomic composition. Hierarchical clustering revealed that 4.3 cm fenced traps formed a terminal branch, as did fenced traps with 11.1 cm diameters (Fig. 12). With unfenced traps excluded, ANOSIMs revealed significant differences in species composition between pairwise combinations of trap sizes (4.3 cm vs. 7.0 cm vs. 11.1 cm diameter) (Tables 5, 7). SIMPER analysis revealed >11 species contributed to the first 50 % of the difference in taxonomic composition between all combinations, with no individual species contributing more than 6.9 % (Table 8).

Effect of trap diameter and fence length at higher taxonomic levels: The results outlined above for species were generally maintained when we repeated our analysis at familial rank. In fact, MDS ordinations obtained at species and family ranks were remarkably similar (Figs. 10 vs. 11). Testing between underlying similarity matrices with the Mantel's test confirmed both were significantly similar

Table 2.—Mean differences obtained from *post-hoc* means comparisons using Scheffé's S for TRAP and FENCE on transformed spider variables for the full data set. Bold text denotes statistically significant difference of *** $P < 0.001$, ** $P < 0.01$ or * $P < 0.05$. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence.

	Effects								
	FENCE						TRAP		
Dependent variables	FL0 vs. FL2	FL0 vs. FL4	FL0 vs. FL6	FL2 vs. FL4	FL2 vs. FL6	FL4 vs. FL6	TD4 vs. TD7	TD4 vs. TD11	TD7 vs. TD11
Abundance	**0.71*** **	**0.96*** **	**1.23*** **	0.25	**0.52*** **	0.27	0.17	**0.54*** **	**0.37** **
Family richness	**0.47*** **	**0.65*** **	**0.85*** **	0.18	**0.37** **	0.20	**0.20* **	**0.45*** **	**0.26** **
Species richness	**0.51*** **	**0.72*** **	**0.92*** **	0.21	**0.41*** **	0.20	**0.20* **	**0.52*** **	**0.32*** **

(sample statistic Rho = 0.879; permuted statistics > Rho = 0; $P < 0.001$). The result of the ANOSIMs reported above at species level also remained unchanged at family rank. The only changed result was in the structuring of 7.0 and 11.1 cm traps with fences in the hierarchical clustering dendrogram.

Determination of an optimal combination of trap size/fence length.—Smoothed species accumulation curves for increasing numbers of traps revealed that different trap size/fence length combinations accrued species at different rates. Fenced traps accumulated species more rapidly than unfenced traps (Fig. 13). Moreover, for each trap size, longer fences accrued species more rapidly. Additionally, species were still being accumulated for all combinations of trap size/fence length as no curves had reached an asymptote (Fig. 13).

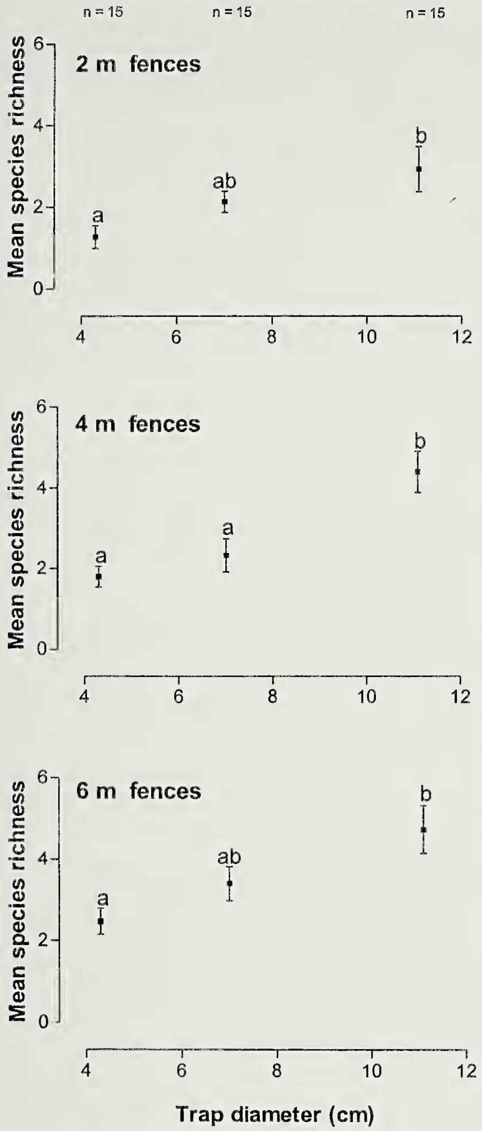
Standardized number of traps: Standardizing at 15 traps revealed large differences in the number of species collected by each trap size/fence length combination (Fig. 13). At 15 traps, 4.3 cm unfenced traps caught only five species, whereas 11.1 cm traps with fences of 4 m or greater collected more than 30 species. Traps with fences generally caught more species than traps without fences. The only exception was the 4.3 cm trap with a 2 m fence, which caught only 10 species compared to the 12 species collected by the 11.1 cm unfenced trap. The 11.1 cm traps with 4 or 6 m fences were considered optimal for a standardized number of traps.

Standardized trap circumference: Standardizing at a cumulative circumference also revealed large differences in the number of species collected by each trap size/fence length combination (Fig. 14). Unfenced traps caught < six species compared to > 10 for fenced traps. Traps with long fences were optimal for this criterion. All traps with 6 m fences and

Table 3.—F-ratios and significance levels from two-way ANOVAs of TRAP and LOCATION or FENCE and LOCATION on transformed spider species richness for data subsets. Bold text denotes statistically significant difference at *** $P < 0.001$, ** $P < 0.01$, * $P < 0.05$.

	Effects				
Data subset	FENCE × LOCATION d.f. 6, 144	TRAP × LOCATION d.f. 4, 144	FENCE d.f. 3, 144	TRAP d.f. 2, 144	LOCATION d.f. 2, 144
Small traps (4.3 cm diameter)	0.994	—	**10.951*** **	—	1.179
Medium traps (7 cm diameter)	**3.567** **	—	—	—	—
Large traps (11.1 cm diameter)	1.120	—	**12.578*** **	—	2.307
Short fences (2 m)	—	1.064	—	**4.498*** **	1.869
Medium fences (4 m)	—	2.257	—	**11.711*** **	**4.056* **
Long fences (6 m)	—	0.337	—	**6.297** **	**4.241* **

5 6 7



Figures 5–7.—Effect of increasing trap diameter on spider species richness for fenced traps with: (5) short fences of 2 m, (6) medium fences of 4 m, or (7) long fences of 6 m. Different lower case letters denote significantly different means (established from *post-hoc* tests on transformed data, Table 4). Error bars are ± one standard error of the mean.

the 11.1 cm diameter trap with a 4 m fence collected high numbers of species (> 16).

Standardized fence length: For fenced traps, standardizing at a cumulative fence length of 24 m revealed large traps generally collected more species. All 11.1 cm traps collected > 13 species, whereas most 7.0 cm and all 4.3 cm diameter traps caught fewer than 11 species (Fig. 15). That said, when each trap diameter was considered separately, and traps were ranked by the number of species collected, traps with 2 m fences always collected the most species (Fig. 15).

Standardized handling time: Standardizing for handling time revealed very different results compared to a standardized number of traps or trap circumference. All traps collected very similar numbers of species (Fig. 16), despite mean handling times differing for each trap size/fence length combination (Table 9). Overall, the 11.1 cm trap with a 4 m fence was optimal, as it could be expected to collect more species than all other traps (>13), during the standardized handling period (Fig. 16). Other subtle differences between trap size/fence length combinations were evident. Firstly, the number of species expected to be collected increased with trap size. Between four to six species were collected from 4.3 cm diameter traps. Six to nine species were caught by 7.0 cm traps. The most species were collected by 11.1 cm traps (8 to 14). Secondly, when each trap size was considered separately, and traps were ranked by the number of species collected, traps with 6 m fences always collected the least.

DISCUSSION

Does adding fences to pitfall traps increase spider catchability in Western Australian jarrah forest?—We found fenced traps caught greater abundance of individuals and more spider families, and species in this habitat. These findings support earlier research in the monsoonal tropics of northern Australia where increased abundances of spiders and dominant taxa were captured in fenced traps compared to unfenced traps (Churchill unpub. data). It is important, however, that the role of trap diameter and fence design be tested in other habitats and over different periods and seasons.

To date, fenced traps have not been widely used to sample spiders. However, they are used frequently to sample amphibians, reptiles and small mammals (Blomberg & Shine 1996; Halliday 1996). For vertebrates, fences increased abundance and species richness of animals collected (Bury & Corn 1987; Morton et al. 1988; Friend et al. 1989), but see Williams & Braun (1983). For invertebrates other than spiders, fenced traps are uncommon. In-

Table 4.—Mean differences obtained from *post-hoc* means comparisons using Scheffé's S for TRAP and FENCE on transformed spider species richness for data subsets. Bold text denotes statistically significant difference of *** $P < 0.001$, ** $P < 0.01$ or * $P < 0.05$. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence.

	Effects								
	FENCE						TRAP		
Data subset	FL0 vs. FL2	FL0 vs. FL4	FL0 vs. FL6	FL2 vs. FL4	FL2 vs. FL6	FL4 vs. FL6	TD4 vs. TD7	TD4 vs. TD11	TD7 vs. TD11
Small traps (4.3 cm diameter)	0.37	**0.58****	**0.79*****	0.21	**0.42***	0.21	—	—	—
Large traps (11.1 cm diameter)	**0.54***	**0.95*****	**1.02*****	0.40	0.47	0.00	—	—	—
Short fences (2 m)	—	—	—	—	—	—	0.33	**0.50***	0.17
Medium fences (4 m)	—	—	—	—	—	—	0.14	**0.69*****	**0.55****
Long fences (6 m)	—	—	—	—	—	—	0.25	**0.56****	0.30

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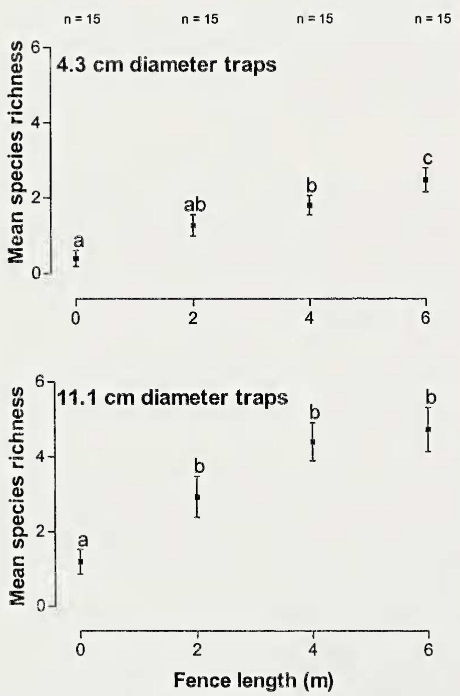

Figures 8–9.—Effect of fencing length on spider species richness for: (8) small traps (4.3 cm diameter), or (9) large traps (11.1 cm diameter). Different lower case letters denote significantly different means (established from post-hoc tests on transformed data, Table 4). Error bars are ± one standard error of the mean.

creases in abundance and species richness of beetles collected with fenced traps, however, have been documented (Durkis & Reeves 1982; Morrill et al. 1990; Crist & Wiens 1995).

Our study revealed marked differences in taxonomic composition between fenced and unfenced traps. This may have arisen because pitfall traps preferentially sample species moving actively across the ground surface. Adding fences my skew this bias further towards the most active species. It will be these species most likely to encounter fences and, by following the fence, fall into the trap. For example, SIMPER analysis revealed the nicodamid *Ambicodamus marae* made the highest contribution to the dissimilarity between fences and unfenced traps. This species had a mean abundance of 5.22 across fenced traps but was not collected at all in unfenced traps (Table 7). Given that of the 47 individuals collected, 45 were adult males, it is likely that at the time of our sampling, males were actively searching for mates thus leading to high captures in fenced traps. Similar results of species-specific differences in catchability between unfenced traps and fenced traps have been documented for beetles (Morrill et al. 1990).

How does trap size influence spider catchability for fenced and unfenced traps?—Generally, higher abundances and more species were collected as trap size increased, however, differences between each

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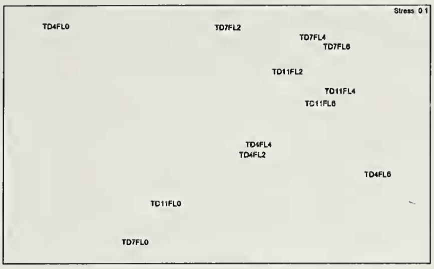

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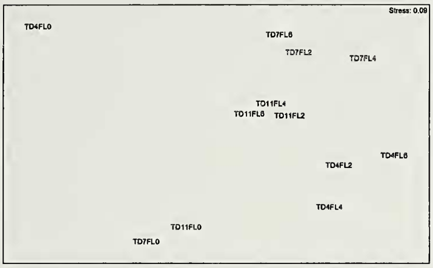

Figures 10–11.—Ordinations showing similarity in spider community composition between each fence length/trap size combination at (10) species and (11) family ranks. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence.

trap size were not always present (Figs. 3–7). Absent in the fenced 2 and 6 m data subsets, but present in the full dataset, were significant differences between 4.3 versus 7.0 cm traps, and between 7.0 versus 11.1 cm traps. Removal of significant differences most likely arose through a loss of power associated with fewer replicates. Greater captures from large pitfall traps with fences compared to small pitfall traps with fences has been found also for reptiles (Morton et al. 1988).

For fenced traps, the primary factor influencing taxonomic composition was trap size; fence length had no significant effect. ANOSIMs revealed significant differences between each trap size for fenced traps, but no differences between traps with 2, 4 or 6 m fences. Reasons behind differences in taxonomic composition between trap sizes for fenced traps are not obvious. They arose from combined contribution of subtle differences in the abundances of many species, rather than a limited few. Some species were preferentially collected in smaller traps. For example, Salticidae Genus 9 sp. 01 was collected in high abundance in 4.3 cm traps, intermediate abundance in 7.0 cm traps and in low abundance in 11.1 cm traps (Table 9). Conversely, other species such as *Ambicodamus marae*, were biased against 4.3 cm traps, but didn't discriminate between 7.0 or 11.1 cm traps. Finally, some species were captured predominantly in intermediate sized 7.0 cm traps (e.g. *Hestimodema* sp. 02 and *Myrmopopaea* sp. 01). Other species were biased against this trap size (e.g. Salticidae Genus 3 sp. 02). We interpret these findings as arising from species-specific differences in behavior that preferentially predisposed individual species to capture (or prevented escape) by each individual trap size.

For unfenced traps, even for very small sample sizes, trap diameter can have a major influence on spider abundance and species richness. Our earlier findings revealed greater captures with increasing trap size when we compared 4.3, 7.0, 11.1 and 17.1 cm diameter traps (Brennan et al. 1999). In particular, mean abundance and species richness differed significantly between the three largest traps. For other invertebrates, size of unfenced traps can also influence captures. Larger traps have yielded greater abundance and species richness of ants and beetles (Luff 1975; Abensperg-Traun & Steven 1995). However, for both groups trap size influenced taxonomic composition. For example, small trap sizes preferentially sampled small beetles and large traps were better for large species (Luff 1975). Similar results were obtained in the present study. Spider taxonomic composition differed markedly between unfenced 4.3 cm versus unfenced 7.0 and 11.1 cm diameter traps. The later trap sizes clustered together tightly in ordinations.

The above finding highlights the difficulties of making valid comparisons between studies using different sampling protocols. Here we can but echo earlier calls for arachnologists to standardize sampling protocols thereby permitting more valid comparisons to be made (Coddington et al. 1991; Churchill 1993; New 1999).

How does fence length influence spider catchability for fenced traps?—Increasing fence length yielded increased spider abundance plus the richness of families and species in our full data set. In fact, traps with 6 m fences had greater captures than those with 2 m fences for all of these variables. Greatest

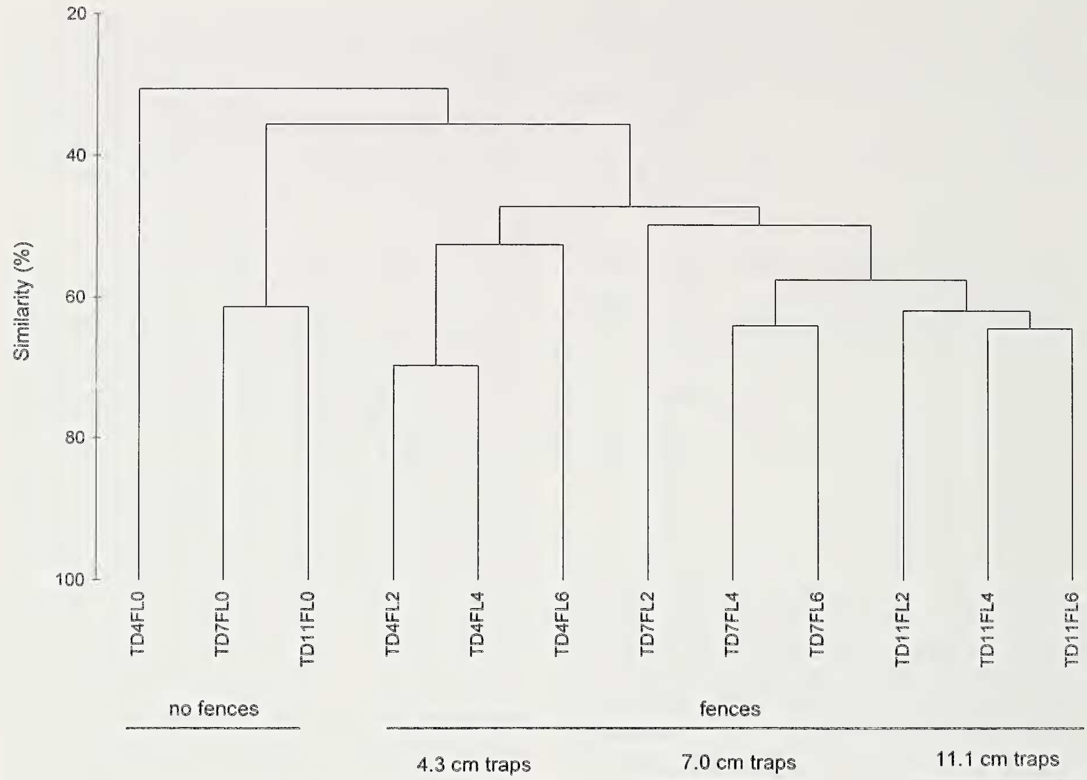

Figure 12.—Dendrogram for hierarchical clustering (group-average linking) of similarity in spider species composition between each fence length/trap size combination.

increases, however, occurred between unfenced traps and those with 2 m fences (our smallest length of fence). Given these findings, two questions arise. Firstly, what is the minimum length of fence required to derive the initial rapid increase in captures? Secondly, at what length of fence will no additional benefit be gained by adding more fence? The former cannot be answered from our dataset. We suggest future workers test the effectiveness of fences over a wider range of lengths. These should include very short fences of perhaps only 10 to 20 cm (5 to 10 cm each side of the trap). With respect to the second question, our results differed between data sets.

When fence length was considered separately in data subsets for 4.3 and 11.1 cm diameter traps, the rate of increase in species

Table 5.—ANOSIM global test results for difference in species composition between various combinations of trap diameter and fence lengths. Bold text denotes statistically significant differences in taxonomic composition at ** $P < 0.01$ or * $P < 0.05$. [a] denotes all possible permutations used. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence.

Data set used	Factors	Global R	Permutations available	Permuted statistics > global R
All trap/fence combinations	FL0 vs. FL2 & FL4 & FL6	0.871	220[a]	**1****
	FL0 vs. FL2 vs. FL4 vs. FL6	0.309	15400[a]	**378***
	TD4 vs. TD7 vs. TD11	0.1	5775[a]	1114
Fenced traps only	TD4 vs. TD7 vs. TD11	0.712	280[a]	**1****

Table 6.—Individual species contributions to the difference in taxonomic composition between fenced and unfenced traps (average dissimilarity = 66.39%), from SIMPER analysis of root transformed standardized data.

Species	Mean abundance		Mean dissimilarity	Contribution (%)	Cumulative contribution (%)
	Unfenced	Fenced			
Ambicodamus marae Harvey 1995	0.00	55.22	4.24	6.38	6.38
Linyphiidae Genus 02 sp. 02	1.33	1.00	3.96	5.96	12.34
Longepi woodman Platnick 2000	0.00	3.89	3.57	5.38	17.73
Supunna funerea Simon 1896	1.33	0.67	3.30	4.97	22.69
Anapidae Genus 01 sp. 02	0.00	2.33	3.04	4.58	27.28
Tasmanoonops sp. 02	0.67	0.44	3.04	4.57	31.85
Hestimodema sp. 02	0.33	2.89	2.82	4.24	36.10
Gnaphosidae Genus 01 sp. 01	0.67	1.67	2.77	4.17	40.27
Elassoctenus sp. 03	0.67	0.22	2.77	4.17	44.44
Salticidae Genus 03 sp. 02	0.67	4.56	2.38	3.58	48.02

richness for additional units of fence differed (Figs. 8 vs. 9). The 4.3 cm diameter traps followed the pattern noted previously in the full data set. Additional increments of fences increased the catch so that traps with 6 m fences had significantly more than those with 2 m fences. Conversely, for 11.1 cm traps no further significant increase in species richness occurred with 4 or 6 m fencing.

For beetles, increasing fence length yields greater abundance. Durkis and Reeves (1982) compared unfenced traps to traps with fences of 0.3, 0.9 or 1.5 m. They found 1.5 m fences collected more beetles than traps with 0.9 m fences and these lengths were superior to 0.3 m fences or unfenced traps (Durkis & Reeves 1982). Other authors report variable effects. Morrill et al. (1990) compared unfenced traps and traps with fences of 0.05, 0.10 or 0.15 m. For some carabid species, abundance did not differ between fenced and unfenced traps. For other species, 0.20 m fences were superior to 0.05 m fences.

For vertebrates, increasing fence length has often been accompanied by increased captures, even for very long fences (Bury & Corn 1987; Friend et al. 1989; Hobbs et al. 1994). Hobbs et al. (1994) reported increased reptile

Table 7.—ANOSIM pairwise tests results for of differences in species composition between various combinations of trap diameter and fence lengths. [a] denotes all possible permutations used. [b] denotes level of statistical significance (*P*) was set at 0.1 owing to the low number of permutations available. Bold text denotes statistically significant differences in taxonomic composition at * $P = 0.1$. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence.

Data set used	Factors and pairwise tests of factor levels	R statistic	Permutations available	Permuted statistics > R statistic
All trap/fence combinations	FL0 vs. FL2 vs. FL4 vs. FL6			
	FL0 vs. FL2	0.481	10[ab]	2
	FL0 vs. FL4	0.778	10[ab]	**1***
	FL0 vs. FL6	0.741	10[ab]	**1***
	FL2 vs. FL4	−0.185	10[ab]	8
	FL2 vs. FL6	0.074	10[ab]	4
	FL4 vs. FL6	−0.111	10[ab]	8
Fenced traps only	TD4 vs. TD7 vs. TD11			
	TD4 vs. TD7	0.741	10[ab]	**1***
	TD4 vs. TD11	0.926	10[ab]	**1***
	TD7 vs. TD11	0.519	10[ab]	**1***

Table 8.—Individual species contributions to differences in taxonomic composition between different trap sizes amongst traps with fences, from SIMPER analysis of root transformed standardized data. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm.

Pairwise comparison	Species	Mean abundance TD4	TD7	TD11	Mean dissimilarity	Contribution (%)	Cumulative contribution (%)
TD4 vs. TD7 (average dissimilarity = 53.17%)	*Hestimodema* sp. 02	0.33	5.67	—	3.67	6.90	6.90
	Gnaphosidae Genus 01 sp. 01	3.00	0.00	—	3.60	6.78	13.67
	Lycidas michaelseni (Simon 1909)	0.00	2.33	—	2.32	4.36	18.03
	Myrmopopaea sp. 01	23.00	14.33	—	2.27	4.27	22.30
	Salticidae Genus 03 sp. 02	4.67	2.67	—	2.26	4.24	26.54
	Ambicodamus marae Harvey 1995	1.33	5.67	—	2.17	4.07	30.61
	Elassoctenus sp. 01	0.33	2.00	—	1.92	3.61	34.22
	Linyphiidae Genus 02 sp. 02	0.00	1.33	—	1.90	3.57	37.80
	Zodariidae Genus 01 sp. 02	0.33	1.33	—	1.80	3.38	41.17
	Longepi woodman Platnick 2000	1.33	4.67	—	1.78	3.35	44.53
	Salticidae Genus 09 sp. 01	1.00	0.33	—	1.78	3.35	47.88
	Opopaea sp. 01	1.67	1.33	—	1.52	2.85	50.73
TD4 vs. TD11 (average dissimilarity = 52.39%)	Anapidae Genus 01 sp. 02	4.00	—	0.67	2.74	5.23	5.23
	Gnaphosidae Genus 01 sp. 01	3.00	—	2.00	2.73	5.21	10.44
	Lycidas michaelseni (Simon 1909)	0.00	—	4.00	2.71	5.16	15.60
	Gnaphosidae Genus 01 sp. 02	0.00	—	2.33	2.14	4.09	19.69
	Lycidas sp. 04	0.33	—	3.67	1.98	3.79	23.48
	Salticidae Genus 09 sp. 01	1.00	—	0.00	1.88	3.59	27.07
	Linyphiidae Genus 02 sp. 02	0.00	—	1.67	1.83	3.49	30.56
	Ambicodamus marae Harvey 1995	1.33	—	8.67	1.80	3.44	34.00
	Hestimodema sp. 02	0.33	—	2.67	1.77	3.37	37.37
	Tasmanoonops sp. 03	0.00	—	1.33	1.59	3.04	40.41
	Myrmopopaea sp. 01	23.0	—	29.0	1.56	2.98	43.39
	Tasmanoonops sp. 02	0.67	—	0.67	1.35	2.59	45.98
	Longepi woodman Platnick 2000	1.33	—	5.67	1.20	2.30	48.27
	Elassoctenus sp. 01	0.33	—	1.00	1.19	2.26	50.54
TD7 vs. TD11 (average dissimilarity = 45.83%)	Gnaphosidae Genus 01 sp. 02	—	0.00	2.33	1.98	4.32	4.32
	Zodariidae Genus 01 sp. 02	—	1.33	0.00	1.94	4.24	8.56
	Hestimodema sp. 02	—	5.67	2.67	1.63	3.55	12.11
	Salticidae Genus 03 sp. 02	—	2.67	6.33	1.58	3.44	15.55
	Anapidae Genus 01 sp. 02	—	2.33	0.67	1.55	3.39	18.93
	Elassoctenus sp. 01	—	2.00	1.00	1.50	3.28	22.22
	Supunna funerea Simon 1896	—	0.00	1.33	1.47	3.21	25.43
	Myrmopopaea sp. 01	—	14.33	29.00	1.38	3.01	28.44
	Gnaphosidae Genus 01 sp. 01	—	0.00	2.00	1.35	2.95	31.39
	Longepi woodman Platnick 2000	—	4.67	5.67	1.33	2.90	34.28
	Lycidas michaelseni (Simon 1909)	—	2.33	4.00	1.29	2.82	37.11
	Opopaea sp. 01	—	1.33	2.33	1.17	2.54	39.65
	Gamasomorpha sp. 02	—	0.00	1.33	1.08	2.36	42.02
	Tasmanoonops sp. 03	—	0.33	1.33	1.06	2.32	44.34
	Linyphiidae Genus 02 sp. 02	—	1.33	1.67	1.04	2.27	46.61
	Lampona brevipes L. Koch 1872	—	0.67	0.00	1.04	2.26	48.87
	Australobus sp. 01	—	1.00	1.33	0.99	2.16	51.04

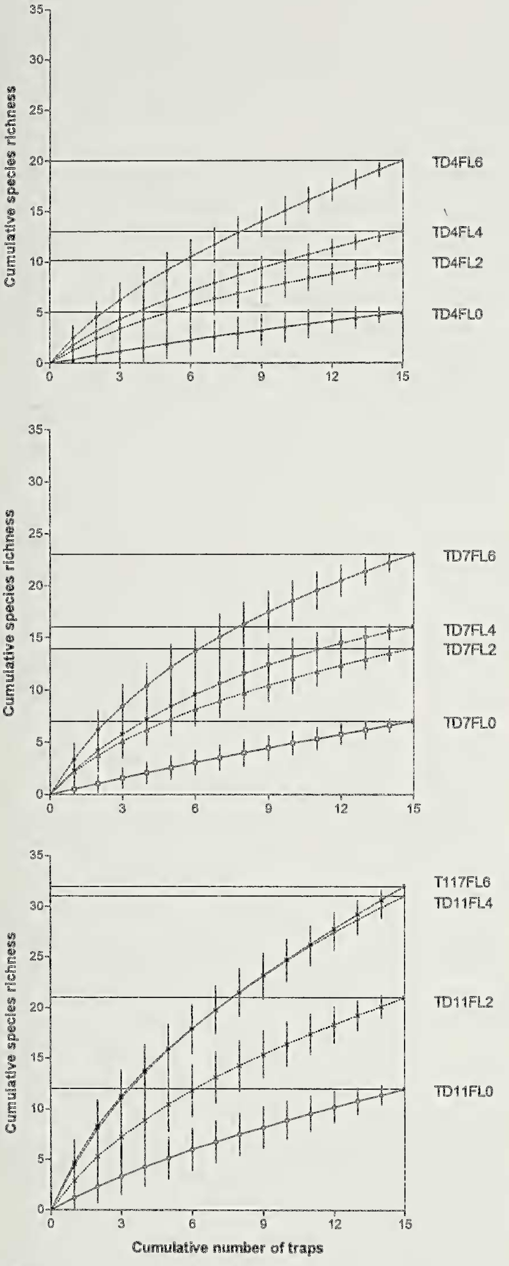

Figure 13.—Smoothed species accumulation curves showing the number of species likely to be sampled with standardized number of traps (15 traps) for each fence length/trap size combination. Error bars are ± one standard deviation of the mean. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence. Curves are spread over three graphs for the purpose of clarity.

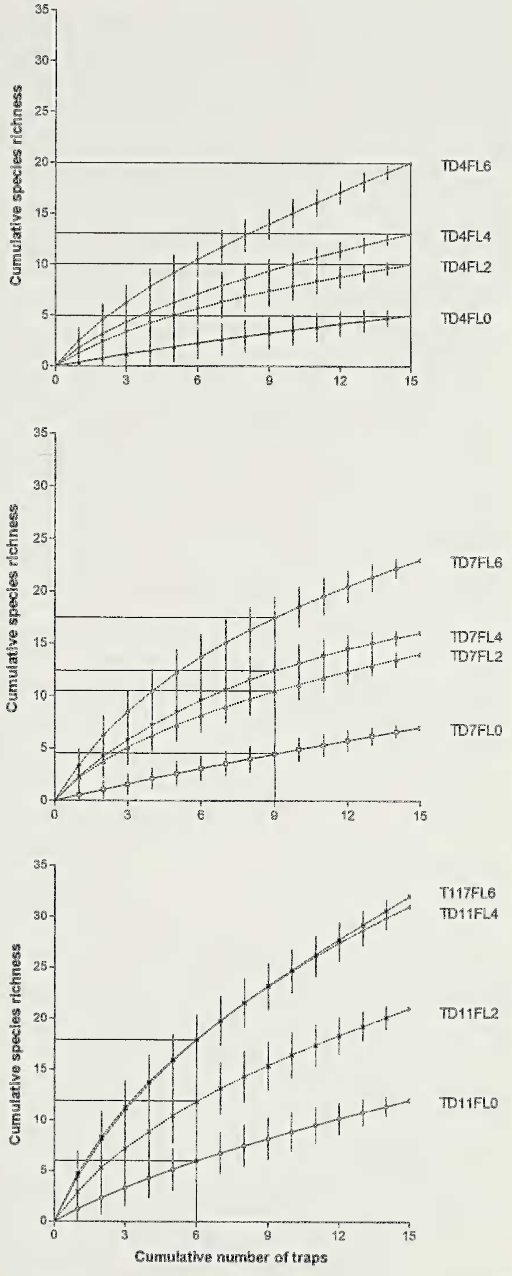

Figure 14.—Smoothed species accumulation curves showing the number of species likely to be sampled with standardized cumulative trap circumference of 206 cm for each fence length/trap size combination. Error bars are ± one standard deviation of the mean. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence. Curves are spread over three graphs for the purpose of clarity.

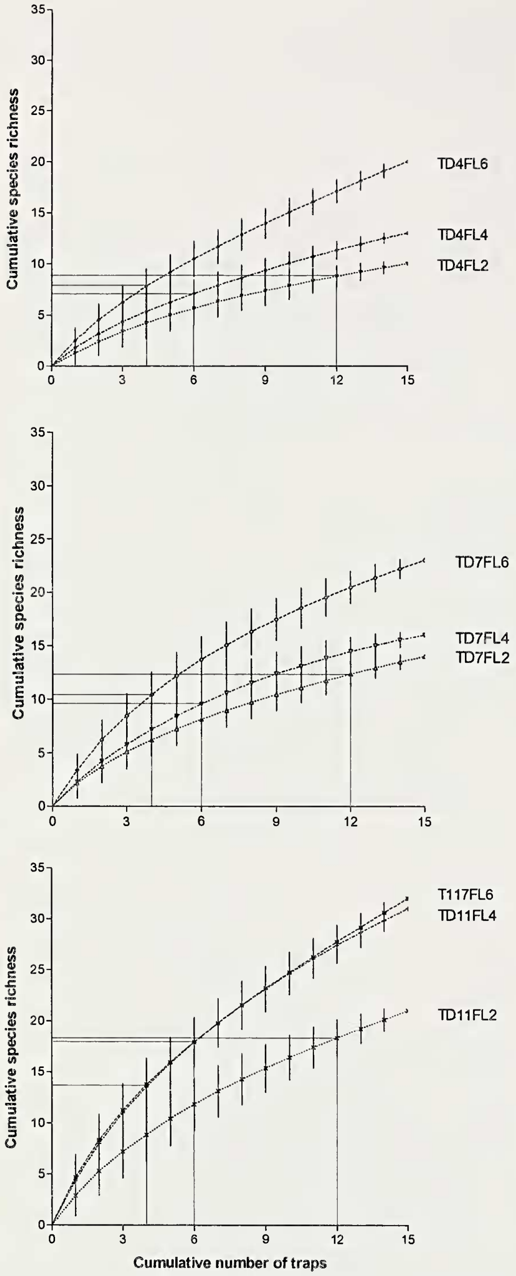

Figure 15.—Smoothed species accumulation curves showing the number of species likely to be sampled with standardized cumulative fence length of 24 m for all trap sizes of fenced traps. Error bars are ± one standard deviation of the mean. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence. Curves are spread over three graphs for the purpose of clarity.

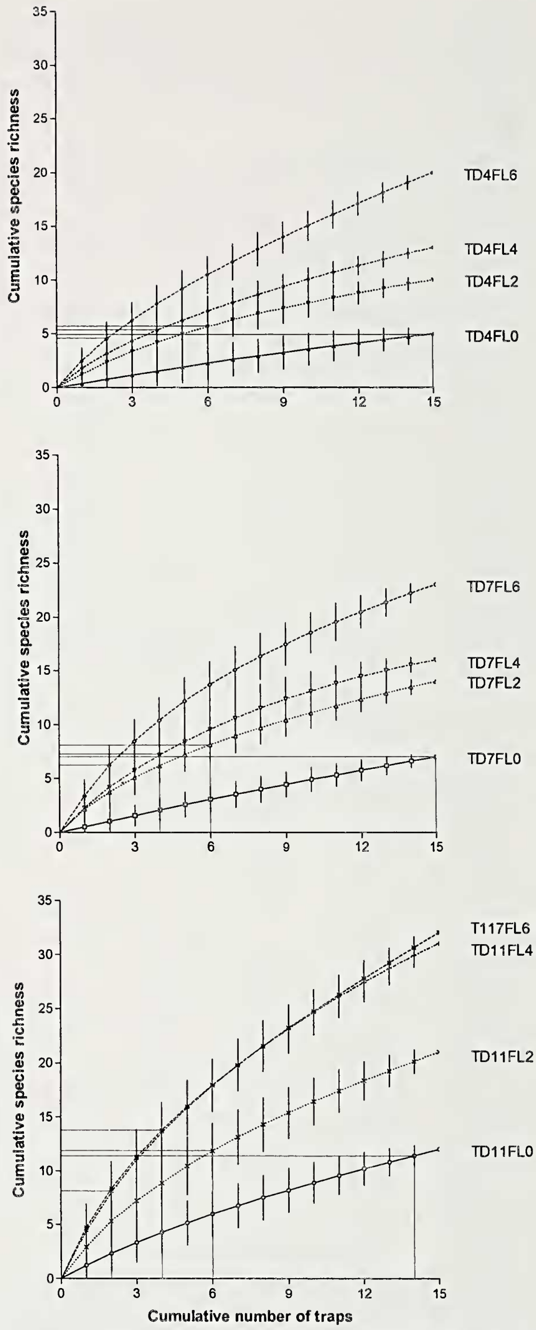

Figure 16.—Smoothed species accumulation curves showing the number of species likely to be sampled with standardized handling time of approximately 23 minutes and 50 seconds for each fence length/trap size combination. Error bars are ± one standard deviation of the mean. TD4 denotes trap diameter 4.3 cm, TD7 denotes trap diameter 7.0 cm, TD11 denotes trap diameter 11.1 cm, FL0 denotes no fence, FL2 denotes 2 m fence, FL4 denotes 4 m fence, FL6 denotes 6 m fence. Curves are spread over three graphs for the purpose of clarity.

captures with 66 m as opposed to 50 m fences. However, Williams and Braun (1983) found no difference in small mammal captures between traps with 0.6 or 1.2 m fences.

Although not the focus of this study, trap location was important for 7.0 cm diameter traps. A significant interaction effect was found between FENCE and LOCATION for species richness (Table 3). This result may have arisen through differences in habitat structure or the influence of trap spacing. Differences in trap arrangement and spacing can influence the abundance, species richness and composition of beetles (Crist & Wiens 1995; Digweed et al. 1995; Ward et al. 2001). The role of trap arrangement and spacing for spiders should be investigated.

Determination of an optimum combination of trap diameter and fence length.—Our results show clearly that some trap diameter/fence length combinations are more efficient than others. For example, results for a standardized fence length suggest that if a total of only 24 m of fence were available, more species might be collected in 12 traps with 2 m fences than in four traps with 6 m fences. This finding is in conflict with Bury and Corn's (1987) statement that "ultimately, the total amount of fence in a [forest] stand is probably more important than individual lengths." It is important to note, however, that in our study the best trap diameter/fence length combination often varied with the efficiency criterion used. For handling time, 11.1 cm trap with a 4 m fence were best. That said, unfenced traps often were very similar in efficiency to fenced traps. This suggests that at our study site during our sampling period, when pitfall trapping with 11.1 cm traps, fieldworkers would be equally justified digging in just six traps with a 2 m fence or 14 unfenced traps. Given this choice, we would much prefer to dig in many unfenced traps for the following reasons. Firstly, although duration of the tasks is similar, digging in many unfenced traps requires much less strenuous physical effort. Secondly, digging in fences causes considerably more physical disturbance and alteration of habitat surrounding the trap. Thirdly, we suspect unfenced traps require less maintenance. As part of a two-year monitoring program of jarrah forest spiders, we have sampled at three monthly intervals using fenced and unfenced traps. Fences have needed repairing constantly owing to disturbance by kangaroos and feral pigs. Branches and twigs falling on fences also have increased the time required to maintain fenced traps in good condition. Fourthly, fences may potentially bias captures by hindering locomotion or changing microhabitats as litter and debris accumulates against them more rapidly than other areas surrounding the trap. Consequently, using drift-fences over many years may allow microhabitats surrounding traps to change more rapidly than traps without fences. For our monitoring program, any litter than had built up against fences was redistributed a week prior to opening the traps. Finally, fences have the potential to inhibit perception of internal spatial heterogeneity within spider communities within a study site. Consolidating individuals from a wider spatial area into a single fenced trap removes patchiness in the occurrence of individuals that would be evident in multiple unfenced traps.

Could other fence designs be more efficient?—The fenced traps we used were single pitfall traps placed in the middle of a straight fence. However, other fence designs exist. The main variations are multiple fences per trap or multiple traps per fence. In the former, a common design is to erect a second fence perpendicular to the first, so that the two fences form a cross with the pitfall trap in the centre. Morrill et al. (1990) found adding a second fence yielded higher captures only for one beetle species. Morton et al. (1988) suspected that adding a second fence was beneficial to increase reptile catch, but their results were inconclusive. Hobbs et al. (1994) showed unequivocally that adding a second fence did not increase reptile captures, despite the extra labor and length of fencing involved. That said, the latter two studies used multiple traps along one or both fences.

With respect to multiple traps per fence designs, perhaps the most common is a straight row of three or more pitfall traps connected by a single straight fence. The success of this design in relation to multiple unfenced traps for spiders has been demonstrated by Churchill (unpub. data) and was discussed previously. How this trap design compares to the simple fenced trap we used is unknown. For small mammals, amphibians and reptiles, however, Friend et al. (1989) found independent traps collected more animals than a mul-

Table 9.—Mean (± S.E.) time periods (minutes:seconds) taken to perform various pitfall trapping activities for different combinations of fence length/trap size.

Activity	Trap/fence combination					
	Fence length (m)					
	0			2		
	Trap diameter (cm)					
	4.3	7.0	11.1	4.3	7.0	11.1
Digging in traps/ fences	0:40 ± 0:02	0:40 ± 0:01	0:44 ± 0:01	3:01 ± 0:07	3:16 ± 0:07	3:11 ± 0:11
Pouring solution into traps	0:10 ± 0:00	0:11 ± 0:00	0:14 ± 0:00	0:10 ± 0:00	0:11 ± 0:00	0:14 ± 0:00
Set traps	0:20 ± 0:00	0:20 ± 0:00	0:20 ± 0:00	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00
Collecting traps	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00
Total	1:35 ± 0:02	1:35 ± 0:01	1:43 ± 0:01	4:01 ± 0:07	4:17 ± 0:07	4:15 ± 0:11

tiple traps per fence design. They attributed this to, firstly, independent traps sampling a wider range of microhabitats and home ranges. Secondly, animals altering their daily movement patterns to avoid the fence during periods when traps were closed. Consequently, when traps were opened, they were less susceptible to capture. Another permutation of the multiple traps per fence design is two traps at either end of a fence. Friend (1984) tested this design against a fenced trap with a single pit (of a different size) that herpetofauna could approach only from one side. Consequently, there are confounding effects and we await a more rigorous test. Theoretically, however, traps placed at either end of fences may be more efficient. There is twice the probability that an animal encountering the fence will turn and move towards a trap, yet the most time consuming component of sampling (digging in the fence) remains constant. This assumes that for an animal encountering a fence, the probability of not turning away before reaching the end of the fence, is equal between fencing types. For longer fences, the probability of following to the fence's end may decline and thereby the greater efficiency of the two-trap fence over the single-trap fence.

Different fencing materials may also influence efficiency. To date, fences have been constructed of plastic, metal roofing and flyscreen. Consequently, considerable variation may be expected in cost, longevity, and time to construct, install plus maintain fences. All may influence handling time efficiency, particularly where regular trapping is undertaken or if long periods elapse between trapping. Here we used black plastic, purchased cheaply from a hardware store on a roll. Although metal roofing was readily available, it costs more per meter, cannot be cut to size easily, and is bulky to transport. Disadvantages may be outweighed, however, if metal fences last longer, require less maintenance or facilitate greater captures. The performance of different fence materials should thus be investigated. When doing so we advocate assessing performance by a number of criteria, of which one should be maintenance/handling time.

Differences in fencing efficiency may vary also between different grades of plastics. In the monitoring program mentioned previously we have used both 100 um and 200 μm thick plastic. Longevity between thickness grades varies considerably. Thicker fences deteriorated approximately twice as rapidly as thinner fences. Thicker fences began to become brittle and pieces of fence flaked off with exposure to sunlight nine months after installation. Conversely, at the end of the monitoring program, most thinner fences did not need replacing. This is not to suggest that thinner fences did not require regular maintenance. We estimate that over the course of monitoring program, even where thin fences were initially installed, half the fences were reinstalled.

Future directions.—The results presented here show clearly that both trap size and fence length can play critical roles in determining spider catch in terms of abundance, species richness and community composition. As such comparisons to date between regions, time periods or studies where pitfall trapping protocols have differed are tenuous. Future devel-

Table 9.—Extended.

Trap/fence combination					
Fence length (m)					
4			6		
Trap diameter (cm)					
4.3	7.0	11.1	4.3	7.0	11.1
5:34 ± 0:14	5:17 ± 0:17	5:26 ± 0:10	8:42 ± 0:14	8:35 ± 0:16	8:35 ± 0:17
0:10 ± 0:00	0:11 ± 0:00	0:14 ± 0:00	0:10 ± 0:00	0:11 ± 0:00	0:14 ± 0:00
0:27 ± 0:00	0:27 ± 0:00	0:27 ± 0:00	0:29 ± 0:01	0:29 ± 0:00	0:29 ± 0:00
0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00	0:25 ± 0:00
6:37 ± 0:14	6:19 ± 0:17	6:32 ± 0:10	9:46 ± 0:15	9:40 ± 0:16	9:43 ± 0:17

opments in statistical analysis may assist in negotiating some of the current plethora of biases and limits to data interpretation where protocols have differed. A more direct and potentially superior line of research, however, is the development of standardized sampling protocols for spiders. The limited resources available to inventory biodiversity require that standardized sampling protocols be highly efficient. Before adopting a standardized pitfall trapping protocol for spiders it must be firmly established that the protocol is more efficient than others in a wide variety of habitat types, and across differing temporal and spatial scales. Currently the data necessary for an informed decision as to what size, preserving solution, spatial arrangement, and duration of sampling etc. to adopt for spiders is lacking. The results presented here are an important step toward identifying the most efficient protocols for trap size and fencing. Nonetheless, studies with sufficient statistical power to determine the interplay of these and other factors in combination remain scarce. The elucidation of factors influencing pitfall trap efficiency represents a priority area for research and the development of a standardized pitfall trapping protocol a key conservation goal for arachnologists.

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LITERATURE CITED

Abensperg-Traun M. & D. Steven. 1995. The effects of pitfall trap diameter on ant species richness (Hymenoptera: Formicidae) and species composition of the catch in a semi-arid eucalypt woodland. Australian Journal of Ecology 20: 282–287.

Adis, J. 1979. Problems of interpreting arthropod sampling with pitfall traps. Zoologischer Anzeiger Jena 202:177–184.

Agosti, D. & L.E. Alonso. 2000. The ALL protocol: A standard protocol for the collection of ground-dwelling ants. Pp. 204–206. *In* Ants: Standard

Methods for Measuring and Monitoring Biodiversity. (D. Agosti, J.D. Majer, L.E. Alonso & T.R. Schultz, eds.). Smithsonian Institution Press, Washington.

Beattie, A.J., J.D. Majer & I. Oliver. 1993. Rapid biodiversity assessment: A review. Pp. 4–14. *In* Rapid Biodiversity Assessment: Proceedings of the Biodiversity Assessment Workshop, 1993 3–4 May, 1993. (Anon., ed.). Macquarie University, Sydney.

Blomberg, S. & R. Shine. 1996. Reptiles. Pp. 218–226. *In* Ecological Census Techniques: A Handbook. (W.J. Sutherland, ed.). The Bath Press, Avon.

Bray, J.R. & J.T. Curtis. 1957. An ordination of the upland forest communities of southern Wisconsin. Ecological Monographs 27:325–349.

Brennan, K.E.C., J.D. Majer & N. Reygaert. 1999. Determination of an optimal pitfall trap size for sampling spiders in a Western Australian Jarrah forest. Journal of Insect Conservation 3:297–307.

Brennan, K.E.C. 2002. The Successional Response of Spider Communities Following the Multiple Disturbances of Mining and Burning in Western Australian Jarrah forest. Ph.D. Thesis, Department of Environmental Biology, Curtin University of Technology, Perth.

Brennan, K.E.C., M.L. Moir & J.D. Majer. 2004. Exhaustive sampling in a Southern Hemisphere global biodiversity hotspot: Inventorying species richness and assessing endemicity of the little known jarrah forest spiders. Pacific Conservation Biology 10:241–260.

Bury, R.B. & P.S. Corn. 1987. Evaluation of pitfall trapping in northwestern forests: Trap arrays with drift fences. Journal of Wildlife Management 51: 112–119.

Chappin III, F.S., E.S. Zavaleta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D.U. Hooper, S. Lavorel, O.E. Sala, S.E. Hobbie, M.C. Mack & S. Díaz. 2000. Consequences of changing biodiversity. Nature 405:234–242.

Churchill, T.B. 1993. Effects of sampling methods on composition of a Tasmanian coastal heathland spider assemblage. Memoirs of the Queensland Museum 33:475–481.

Churchill, T.B. & J.M. Arthur. 1999. Measuring spider richness: Effects of different sampling methods and spatial and temporal scales. Journal of Insect Conservation 3:287–295.

Churchward, H.M. & G.M. Dimmock. 1989. The soils and landforms of the northern jarrah forest. Pp. 13–22. *In* The Jarrah Forest: A Complex Mediterranean Ecosystem. (B. Dell, J.J. Havel & N. Malajczuk, eds.). Kluwer Academic Publishers, Dordrecht.

Clarke, K.R. 1993. Non-parametric multivariate analysis of changes in community structure. Australian Journal of Ecology 18:117–143.

Clarke, K.R. & R.H. Green. 1988. Statistical design and analysis for a 'biological effects' study. Marine Ecological Progress Series 46:213–226.

Coddington, J.A., C.E. Griswold, C.E. Davila, D.S. Penaranda & S.F. Larcher. 1991. Designing and testing sampling protocols to estimate biodiversity in tropical ecosystems. Pp. 44–60. *In* The Unity of Evolutionary Biology: Proceedings of the Fourth International Congress of Systematic and Evolutionary Biology. (E.C. Dudley, ed.). Dioscordes Press, Portland, Oregon, USA.

Coddington, J.A., L.H. Young & F.A. Coyle. 1996. Estimating spider species richness in a southern Appalachian cove hardwood forest. Journal of Arachnology 24:111–128.

Colwell, R.K. 1994–2000. Estimate S: Statistical estimation of species richness and shared species from samples. Version 5. http://viceroy.eeb.uconn.edu/estimates.

Colwell, R.K. & J.A. Coddington. 1995. Estimating terrestrial biodiversity through extrapolation. Pp. 101–118. *In* Biodiversity: Measurement and Estimation. (D.L. Hawksworth, ed.). Chapman and Hall, London.

Crist, T.O. & J.A. Wiens. 1995. Individual movements and estimation of population size in darkling beetles (Coleoptera: Tenebrionidae). Journal of Animal Ecology 64:733–746.

Curtis, D.J. 1980. Pitfalls in spider community studies. Journal of Arachnology 8:271–280.

Cutler, B., L.H. Grim & H.M. Kulman. 1975. A study in the summer phenology of dionychious spiders from northern Minnesota forests. Great Lakes Entomologist 8:99–104.

Day, R.W. & G.P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. Ecological Monographs 59:433–463.

Digweed S.C., Currie C.R., Carcamo H.A. & Spence. J.R. 1995. Digging out the "digging-in effect" of pitfall traps: Influences of depletion and disturbance on catches of ground beetles (Coleoptera: Carabidae). Pedobiologia 39:561–576.

Dobyns, J.R. 1997. Effects of sampling intensity on the collection of spider (Araneae) species and the estimation of spider species richness. Environmental Entomology 26:150–162.

Duffey, E. 1962. A population study of spiders in Limestone Grassland. Journal of Animal Ecology 31:571–599.

Duffey, E. 1972. Ecological survey and the arachnologist. Bulletin of the British Arachnological Society 2:69–82.

Durkis, T.J. & R.M. Reeves. 1982. Barriers increase efficiency of pitfall traps. Entomological News 93:8–12.

Edwards, R.L. 1993. Can the species richness of spiders be determined? Psyche 100:185–208.

Friend, G.R. 1984. Relative efficiency of two pitfall-drift fence systems for sampling small vertebrates. Australian Zoologist 21:423–432.

Friend, G.R., Smith, G.T., Mitchell, D.S. & C.R. Dickman. 1989. Influence of pitfall and drift fence design on capture rates of small vertebrates in semi-arid habitats of Western Australia. Australian Wildlife Research 16:1–10.

Gaston, K.J. & R.M. May. 1992. The taxonomy of taxonomists. Nature 356:281–282.

Gist, C.S. & J.D.A. Crossley. 1973. A method for quantifying pitfall trapping. Environmental Entomology 2:951–952.

Greenslade, P.J.M. 1964. Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). Journal of Animal Ecology 33:301–310.

Greenslade, P.J.M. 1973. Sampling ants with pitfall traps: Digging in effects. Insectes Sociaux 20: 343–353.

Gurdebeke, S. & J.-P. Maelfait. 2002. Pitfall trapping in population genetic studies: Finding the right solution. Journal of Arachnology 30:255–261.

Halliday, T.R. 1996. Amphibians. Pp. 205–217. *In* Ecological Census Techniques: A Handbook. (W.J. Sutherland, ed.). The Bath Press, Avon.

Hawksworth, D.L. 1995. The resource base for biodiversity assessment. Pp. 545–605. *In* Global Biodiversity Assessment. (V.H. Heywood, ed.). United Nations Environment Programme and Cambridge University Press, Cambridge.

Hobbs, T.J., S.R. Morton, P. Masters & K.R. Jones. 1994. Influence of pitfall-trap design on sampling of reptiles in arid spinifex grasslands. Wildlife Research 21:483–490.

Holland, J.M. & S. Smith. 1999. Sampling epigeal arthropods: An evaluation of fenced pitfall traps using mark-release-recapture and comparisons to unfenced pitfall traps in arable crops. Entomologia Experimentalis et Applicata 91:347–357.

Joosse, E.N.G. & J.M. Kapteijn. 1968. Activity stimulating phenomena caused by field disturbance in the use of pitfall traps. Oecologia 1: 385–392.

Luff, M.L. 1975. Some features influencing the efficiency of pitfall traps. Oecologia 19:345–357.

Main, B.Y. 1976. Spiders. Collins, Sydney.

Manly B.F.J. 1994. Multivariate Statistical Methods: A Primer. 2nd Edition. Chapman & Hall, London.

May, R.M. 1988. How many species are there on Earth? Science 241:1441–1449.

Melbourne, B.A. 1999. Bias in the effect of habitat structure on pitfall traps: An experimental evaluation. Australian Journal of Ecology 24:228–239.

Merrett, P. 1967. The phenology of spiders on heathland in Dorset: I. Families Atypidae, Dysderidae, Gnaphosidae, Clubionidae, Thomisidae and Salticidae. Journal of Animal Ecology 36: 363–374.

Merrett, P. 1968. The phenology of spiders on heathland in Dorset: II. Families Lycosidae, Pisauridae, Agelinidae, Mimetidae, Theridiidae, Tetragnathidae, Argiopidae. Journal of Zoology (London) 156:239–256.

Merrett, P. 1983. Spiders collected by pitfall trapping and vacuum sampling in four stands of Dorset heathland representing different growth phases of heather. Bulletin of the British Arachnological Society 6:14–22.

Merrett, P. & R. Snazell. 1983. A comparison of pitfall trapping and vacuum sampling for assessing spider faunas on heathland at Ashdown Forest, south-east England. Bulletin of the British Arachnological Society 6:1–13.

Mommertz, S., C. Schauer, N. Koesters, A. Lang & J. Filser. 1996. A comparison of D-vac suction, fenced and unfenced pitfall trap sampling of epigeal arthropods in agro-ecosystems. Annales Zoologici Fennici 33:117–124.

Morrill, W.L., D.G. Lester & A.E. Wrona. 1990. Factors affecting the efficiency of pitfall traps for beetles (Coleoptera: Carabidae and Tenebrionidae). Journal of Entomological Science 25:284–293.

Morton, S.R., M.W. Gilliam, K.R. Jones & M.R. Flemming. 1988. Relative efficiency of different pit-trap systems for sampling reptiles in spinifex grasslands. Australian Wildlife Research 15:571–577.

Muma, M.H. & K.E. Muma. 1949. Studies on a population of parry spiders. Ecology 30:173–196.

New, T.R. 1999. Untangling the web: Spiders and the challenges of invertebrate conservation. Journal of Insect Conservation 3:251–256.

Niemelä, J., E. Halme, T. Pajunen & Y. Haila. 1986. Sampling spiders and carabid beetles with pitfall traps: The effects of increased sampling effort. Annales Zoologici Fennici 52:109–111.

Niemelä, J., J. Kotze, A. Ashworth, P. Brandmayr, K. Desender, T. New, L. Penev, M. Samways & J. Spence. 2000. The search for common anthropogenic impacts on biodiversity: A global network. Journal of Insect Conservation 4:3–9.

Pimm, S.L. & P. Raven. 2000. Biodiversity: Extinction by numbers. Nature 403:843–845.

Primer E. 2001. Primer 5 for Windows. Version 5.2.2. Plymouth Marine Laboratory, Plymouth.

Purvis, A. & A. Hector. 2000. Getting the measure of biodiversity. Nature 405:212–219.

Raven, P.H. & E.O. Wilson. 1992. A fifty-year plan for biodiversity surveys. Science 258:1099–1100.

Riecken, U. 1999. Effects of short-term sampling on ecological characterization and evaluation of epigeic spider communities and their habitats for site assessment studies. Journal of Arachnology 27:189–195.

Samu, F. & G.L. Lövei. 1995. Species richness of a spider community (Araneae): Extrapolation from simulated increasing sampling effort. European Journal of Entomology 92:633–638.

Samu, F. & M. Sárospataki. 1995. Design and use of a hand-held suction sampler, and its comparison with sweep net and pitfall trap sampling. Folia Entomologica Hungarica 56:195–203.

Skerl, K. & R. Gillespie. 1999. Spiders in conservation: Tools, targets and other topics. Journal of Insect Conservation 3:249–250.

Southwood, T.R.E. 1966. Ecological Methods with Particular Reference to the Study of Insect Populations. Methuen, London.

Spence, J.R. & J.K. Niemelä. 1994. Sampling carabid assemblages with pitfall traps: The madness and the method. Canadian Entomologist 126:881–894.

SPSS. 1996. SPSS 7.5 for Windows. SPSS Incorporated.

Standen, V. 2000. The adequacy of collecting techniques for estimating species richness of grassland invertebrates. Journal of Applied Ecology 37:884–893.

Stork, N.E. & M.J. Samways. 1995. Inventorying and monitoring biodiversity. Pp. 453–543. *In* Global Biodiversity Assessment. (V.H. Heywood, ed.). United Nations Environment Programme and Cambridge University Press, Cambridge.

Topping, C.J. & M.L. Luff. 1995. Three factors affecting the pitfall catch of linyphiid spiders (Araneae: Linyphiidae). Bulletin of the British Arachnological Society 10:35–38.

Topping, C.J. & K.D. Sunderland. 1992. Limitations to the use of pitfall traps in ecological studies exemplified by a study of spiders in a field of winter wheat. Journal of Applied Ecology 29: 485–491.

Turnbull, A.L. 1973. Ecology of the true spiders (Araneomorphae). Annual Review of Entomology 18:305–348.

Uetz, G.W. & J.D. Unzicker. 1976. Pitfall trapping in ecological studies of wandering spiders. Journal of Arachnology 3:101–111.

Underwood, A.J. 1997. Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance. Cambridge University Press, Cambridge.

Ward D.F., New T.R. & Yen A.L. 2001. Effects of pitfall trap spacing on the abundance, richness and composition of invertebrate catches. Journal of Insect Conservation. 5:47–53.

Williams, D.F. & S.E. Braun. 1983. Comparison of pitfall and conventional traps for sampling small mammal populations. Journal of Wildlife Management 47:841–845.

Wilson, E.O. 1985. The biodiversity crisis: A challenge to science. Issues in Science and Technology 2:20–29.

Work T.T., Buddle C.M., Korinus L.M. & Spence J.R. 2002. Pitfall trap size and capture of three taxa of litter-dwelling arthropods: Implications for biodiversity studies. Environmental Entomology 31:438–448.

Zar, J.H. 1984. Biostatistical Analysis. Second Edition. Prentice-Hall, Englewood Cliffs, New Jersey.

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